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PHOTOLUMINESCENCE AND DOUBLE-CRYSTAL X-RAY STUDY OF InGaAs/InP: EFFECT OF RARE EARTH (DYSPROSIUM) ADDITION DURING LIQUID PHASE EPITAXIAL GROWTH*

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High purity $In_{0.53}Ga_{0.47}As$ layers were grown on semi-insulating InP:Fe substrates by liquid phase epitaxy by adding small amounts of dysprosium (rare earth) to the melt. Hall effect and photoluminescence measurements showed that the addition of Dy strongly reduced the carrier and residual donor concentration, with a concurrent shift of the excitonic luminescence toward higher energies. The observed effects are ascribed to the gettering of residual donor impurities in the melt by Dy, as well as to the effects of possible incorporation of Dy into the grown layers.

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1. Introduction

High purity $In_{0.53}Ga_{0.47}As$ layers were grown on semi-insulating InP substrates by liquid phase epitaxy (LPE). High purity was achieved by adding small amounts of rare earth element (REE) dysprosium (Dy) to the melt. REEs form stable compounds with the donor type impurities which are insoluble in the indium melt, thus preventing their incorporation into the grown layers, leading to the suppression of the unintentional residual donor impurities (or gettering effect) [1–3]. REEs can also be incorporated into the lattice, which might lead to the modification of mismatch strains in the heteroepitaxial layer.

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The aim of this work was to investigate the effect of the variation of the Dy doping level on the properties of InGaAs layers on InP, in order to obtain a better understanding of the underlying mechanisms. A more detailed account will be published elsewhere [4].

2. Liquid phase epitaxial layer growth and characterization

LPE $In_{0.53}Ga_{0.47}As$ layers were grown on (100) oriented semi-insulating InP:Fe substrates with various amounts of Dy (up to 0.15 atomic per cent) added to the melt, in a conventional multiple-well horizontal graphite slider boat and quartz tube epitaxial growth apparatus in Pd-purified flowing hydrogen atmosphere [5]. Before the growth the InP substrates were etched in 2 per cent Br-methanol for 2 minutes.

The source materials were 6N In and Bridgman and Czochralski grown GaAs and InAs single crystals ($n \approx 10^{16}$ cm^{-3}). The atomic fractions of the growth solutions were $x_{As} = 0.051$ and $x_{Ga} = 0.022$, respectively, calculated for the liquidus temperature of 630°C [6]. Indium was prebaked at 700°C for 20 hours, then weighed InAs and GaAs were added to the melt to form the growth solution, which was baked again at 700°C for 40–64 hours. Then Dy was added and the melt was baked for the third time at 690–700°C for 20 hours. The $In_{0.53}Ga_{0.47}As$ layers were grown at 625°C by using a step cooling technique with 5°C supercooling. 5–6 minutes of growth resulted in 3–5 μm thick layers.

The grown layers were characterized by various methods. Double-crystal X-ray diffraction (DCXRD) was performed on the layers and the (004) reflection rocking curves were recorded. Hall effect and conductivity measurements were performed using the Van der Pauw technique at 300 K and 77 K. Near band edge photoluminescence (PL) spectra, excited by a Kr ion laser, were recorded at 4.4 K, using a 1 m monochromator coupled to a cooled Ge detector [7].

3. Results and discussion

The relaxed lattice mismatch was obtained from the DCXRD data with corrections for the tetragonal distortion [8]. The grown $In_{0.53}Ga_{0.47}As$ layers were slightly in compression (In-rich side of the growth) (cf. Table), and the lattice mismatch decreased with an increasing amount of Dy added to the melt.

Figure 1 presents the 300 K carrier concentration data versus the Dy concentration in the melt (cf. also Table). With an increasing amount of Dy the electron concentration in the layers decreased from about 1×10^{17} cm^{-3} when no Dy was added, to $(2\text{–}5)\times10^{16}$ cm^{-3} for 0.005-0.01 atomic percent Dy, while 0.02–0.05 atomic percent added Dy decreased it further to $(2-10)\times10^{14}$ cm^{-3}, then resulted in a conversion to p-type with a hole concentration of $(2\text{–}20)\times10^{14}$ cm^{-3} above 0.03–0.07 atomic per cent Dy. The behaviour in this range, however, is influenced by the exact value of the residual acceptor concentration.

Using the measured mobilities (cf. Table), the concentration of ionized donors (N_D) and acceptors (N_A) was estimated from the appropriate theoretical curves [9, 10], allowing the separate determination of N_D and N_A for each layer (see Table). The concentration of uncontrolled background acceptors remained roughly

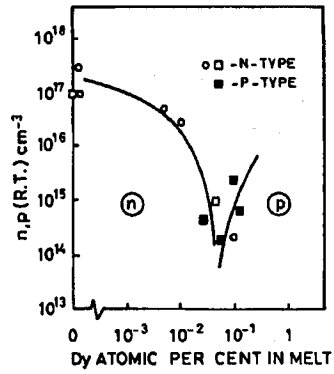

Fig. 1. 300 K carrier concentration versus the Dy content in the melt.

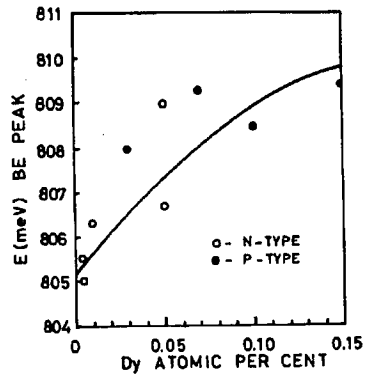

Fig. 2. 4.4 K bound exciton energy versus the Dy content in the melt.

TABLE

Relaxed lattice mismatch, room temperature carrier concentration and mobility, and bound exciton peak positions at 4.4 K for representative InGaAs layers.

Sample	Dy atomic per cent	da/a [10^{-4}]	n or p [cm^{-3}]	μ [cm^2/(V s)]	N_D [cm^{-3}]	N_A [cm^{-3}]	BE [meV]
1115	none	4.9	(n)1.0 x 10^{17}	7470	1.1 x 10^{17}	1 x 10^{16}	801.1
0215	0.005	1.79	(n)5.6 x 10^{16}	7360	8.8 x 10^{16}	3.2 x 10^{16}	805.0
0225	0.01	2.32	(n)2.8 x 10^{16}	8200	4.5 x 10^{16}	1.7 x 10^{16}	806.3
1111	0.05	2.3	(n)1.0 x 10^{15}	9960	7.5 x 10^{15}	6.5 x 10^{15}	809.0
1117A	0.07	1.6	(p)3 x 10^{14}	180	–	–	809.3
0303	0.10	1.31	(n)2.1 x 10^{14}	9450	1 x 10^{16}	1 x 10^{16}	805.8
1112	0.10	1.6	(p)2.5 x 10^{15}	210	–	–	808.5
1117B	0.15	0.95	(p)7.5 x 10^{15}	175	–	–	809.0

constant at the level of $(1–3)\times10^{16}$ cm^{-3}. Up to about 0.01–0.02 atomic per cent Dy in the melt the donor concentration decreased roughly in proportion with the Dy content, then reached the level of uncontrolled acceptor concentrations, resulting in closely compensated n-type and for a further increase in the amount of Dy, in compensated p-type layers.

At 4.4 K the PL spectra consisted of three bands, a bound exciton (BE) line at 800–809 meV, a donor-to-acceptor band at about 786 meV assigned to Si on As-site acceptors, and a band assigned to the phonon replica of the donor-to-acceptor band at about 754 meV. The positions of the BE lines shifted to higher energy with increasing amount of Dy added to the melt during the crystal growth (see Fig. 2 and Table). The half-width of the BE line decreased strongly with increasing Dy concentrations for low concentrations of Dy, and saturated above about 0.03 atomic per cent Dy, at a value of 3–3.5 meV which is comparable with the best reported values for layers grown by LPE [11].

4. Summary

In conclusion, the above experimental observations, i.e. the decrease in lattice mismatch and in donor impurity concentration, and the upward shift of the bound exciton line toward values corresponding to lattice match as well as the decrease in the width of the excitonic line with increasing amount of Dy in the melt can be satisfactorily interpreted by the effect of gettering of unintentional donor impurities in the melt by Dy, as well as by the effect of strain modification in the layers due to the incorporation of Dy.

References

[1] N.T. Bagraev, L.S. Vlasenko, K.A. Gatsoev, A.T. Gorelonok, A.V. Kamatin, V.V. Mamutin, B.V. Pushnyi, V.K. Tibilov, Yu.P. Tolparov, A.E. Shubin, *Fiz. Tekh. Poluprovodn.* **18**, 83 (1984) [*Sov. Phys.–Semicond.* **18**, 49 (1984)].

[2] A.T. Gorelenok, V.G. Gruzdov, R. Kumar, W.W. Mamutin, A.T. Polianskaya, I.G. Saveliev, Yu.W. Shmarcev, *Fiz. Tekh. Poluprovodn.* **22**, 35 (1988) [*Sov. Phys.–Semicond.* **22**, 28 (1988)].

[3] A. Kumar, D.N. Bose, *Mater. Sci. Eng. B* **12**, 389 (1992).

[4] L. Csontos, D. Vignaud, B. Pödör, K. Somogyi, to be published.

[5] J. Pfeifer, L. Andor, L. Csontos, Z. Labadi, K. Wlodarczyk, in: *Proc. 3rd European Conf. on Crystal Growth, Budapest 1991*, Ed. A. Lörinczy, Part II, Trans Tech. Publ., Zürich 1991, p. 496.

[6] K. Sakai, Y. Matsushima, S. Akiba, T. Yamamoto, *Jpn. J. Appl. Phys.* **18**, 1009 (1979).

[7] D. Vignaud, X. Wallart, F. Mollot, *J. Appl. Phys.*, in press.

[8] I.C. Bassignana, C.J. Miner, N. Puetz, *J. Appl. Phys.* **65**, 4299 (1989).

[9] Y. Takeda, in: *GaInAsP Alloy Semiconductors*, Ed. T.P. Pearsall, Wiley, New York 1982, Ch. 9.

[10] L.F. Eastman, in: *Properties of Lattice Matched and Strained InGaAs*, Ed. P. Bhattacharya, INSPEC, London 1993, Ch. 4.1.

[11] D. Bimberg, B. Srocka, in: *Properties of Lattice Matched and Strained InGaAs*, Ed. P. Bhattacharya, INSPEC, London 1993, Ch. 6.1.